Prov #1

Exhibit B

COVER PAGE

VERMONT EPSCoR "Phase 0" SBIR PROPOSAL

NAME OF FIRM
Green Mountain Radio Research Company

Year(s) I have previously submitted a Phase 0: None

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TITLE OF PROJECT
Electronically tunable high-efficiency power amplifiers

TECHNICAL ABSTRACT (LIMIT TO 200 WORDS)

The generation of power at radio frequencies (RF) is required in a number of applications. These include not only the well-known radio/cellular/PCS communications, but also RF heating, plasma generation, RF lighting, and magnetic-resonance imaging. Efficiency in the dc-to-RF conversion process is important in most applications, results in reduced size and weight and/or increased talk time without changing batteries. Techniques for efficient RF-power amplification have been developed. Unfortunately, all require precise tuning and matching of the output to the amplifier, and in most applications, the loads vary over time, making retuning a constant need. Motor-driven and relay-based tuners have been developed, but are generally too slow and bulky, and consume too much power.

This proposed Phase-0 investigation will investigate the feasibility of an an electronically tunable high-efficiency power amplifier. The results of this investigation and experiment are expected to be very helpful in securing a Phase-I SBIR contract from DoD, DoE, or NASA.

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)
Amplifier, power, efficiency, tunable, semiconductor

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Frederick H Raab   March 22, 1999

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1. INTRODUCTION

The generation of power at radio frequencies (RF) is required in a number of applications. These include not only the well-known radio/cellular/PCS communications, but also RF heating, plasma generation, RF lighting, and magnetic-resonance imaging (MRI). In most applications, an "RF power amplifier" (PA) converts direct-current (dc) energy from a power supply into RF energy.

Efficiency in the dc-to-RF conversion process is important in most applications, much as miles per gallon is important in a vehicle. In some cases, the benefits are economic (lower cost of operation). In others, they are reduced size and weight and/or increased talk time without changing batteries. There are also collateral environmental benefits. Reduced electricity consumption means reduced power-plant emissions, and reduced battery usage means reduced hazardous-waste production and disposal.

Techniques for efficient RF-power amplification have been developed by the principal investigator at GMRR. Unfortunately, all require precise tuning and matching of the output to the amplifier, which is somewhat analogous to the use of the gear shift in a vehicle to match the engine speed to the wheel speed. In most applications, the loads vary over time, making retuning a constant need. Motor-driven and relay-based tuners have been developed, but are generally too slow and bulky, and consume too much power.

Many semiconductors including those used for RF-power amplification (e.g., MOSFETs) exhibit voltage-dependent capacitances which in principle can be used for electronic tuning. Since such tuning devices are expected to be small, to use little power, and to be rapidly retunable under automatic control. GMRR proposes to use the EPSCoR grant to perform a preliminary feasibility investigation and proof-of-concept experiment. The results of this investigation and experiment are expected to be very helpful in securing a Phase-I SBIR contract from DoD, DoE, or NASA.

2. TECHNICAL DISCUSSION

This short technical discussion gives an overview of the applications, amplifiers, and proposed concept.

Applications

RF heating is used in a variety of manufacturing applications to cure metal, wood, and plastic pieces. A high-power RF signal creates a high-intensity RF field, which in turn heats the object to be processed. For example, two plastic pieces so heated bond together. Delivery of power to the load (typically a "work coil") requires tuning and matching. However, the load changes as the object moves in and out of the RF field and as its temperature changes.

Plasma generators use high-power RF to create an intense magnetic-field

that ionizes the gas in the plasma chamber. A typical application is semiconductor processing. A potential new application is RF lighting. In this application, an external coil generates a field that ionizes the gas in a small bulb. The ionized gas then radiates visible light (metal vapor) or ultraviolet light (fluorescent lighting). The advantages of RF lighting include small size, reduced power consumption, and long life.

RF power amplifiers are used in virtually all radio transmitters from broadcast through cellular. Efficiency is of interest in most of these applications. In high-power fixed broadcast transmitters, it reduces operating costs, while in mobile and cellular applications it extends talk time and reduces the need for batteries. Unfortunately, most mobile and cellular applications subject the transmitting antenna to a changing environment, resulting in the need for constant retuning to achieve high efficiency.

High-Efficiency Amplifiers

Power amplifiers with the capability to approach 100-percent dc-to-RF conversion efficiency are designated classes D, E, and F.

Class-D power amplifiers (PAs) employ two transistors in a push-pull configuration. The transistors are driven to act as switches and generate a square-wave voltage. The fundamental-frequency component of the square wave is passed to the load through an output filter. The output filter must be tuned for the frequency of operation, although a T filter developed at GMRR requires only a single adjustment to change frequency. Charging and discharging of the drain capacitances typically limit class D to HF and lower VHF.

The class-E power amplifier consists of a single transistor and a load network. The load network includes an RF choke, a drain-shunt capacitor, and a series-tuned output filter that prevents harmonics from reaching the load. The transistor is operated as a switch and class-E operation is produced by an interaction between the switching and the transient response of the load network. Proper adjustment of the load network and shunt capacitance results in discharge of the drain capacitance at the transistor turn-on time. This allows class E to achieve high efficiency at frequencies into the lower microwave region. The disadvantage is that a minimum of two adjustments must be made to the load network to change frequency.

Class-F power amplifiers use specified sets of harmonic resonators to shape the drain voltage or current waveform to reduce power dissipation, thereby increasing efficiency. The most commonly used configuration shapes voltage toward a square wave and current toward half of a sine wave. Since the load networks must produce specified impedances at multiple frequencies, their adjustment is often more difficult than those for classes D and E.

Electronic Tuning

Electronically tunable components will make possible much wider use of high-efficiency power amplifiers. The voltage-variable characteristic of semiconductor junctions offers, in principle, a means of electronic tuning. Basically, variation of a dc bias voltage changes the capacitance, which in turn changes the tuning of the output filter. In practice today, however, such "varactor" diodes are used only in low-power applications such as receivers.

High-power amplifiers are today tuned by either (a) manually adjusted components as shown in Figure 1, (b) relay-selected components, or (c) pin-diode-selected components. The first two approaches work well, but are slow and large. Tuners based upon pin-diode switches can react relatively quickly. However, they require a relatively large number of components, are expensive, and require complex control systems.

It may be possible to develop components especially designed for high-power electronic tuning. However, it is possible that the voltage-dependent capacitance inherent in RF-power transistors can itself be used for high-power tuning. These devices are relatively small and have ratings suitable for handling significant power. If this concept were proven feasible, electronic tuning could be implemented with off-the-shelf components.

3. WORK PLAN

The purpose of the proposed Phase-0 investigation is to determine the feasibility of high-power electronic tuning using off-the-shelf components. The effort is divided into the three tasks outlined below. Labor hours and associated costs are given in Section 10. The proposed investigation will be scheduled over a three-month period (tentatively May - July 1999).

A class-E design has the potential of good efficiency and the need for only two tunable elements (Figure 2). To conserve costs, the investigation will use low-cost transistors suitable for use at HF rather than the more expensive and more fragile transistors used for VHF and UHF.

Task 1. Transistor Characteristics

Obtain transistors. Construct test fixture breadboard. Measure drain capacitance vs. voltage [$C(V)$] characteristics.

Task 2. Design Amplifier

Use $C(V)$ data from Task 1 to design amplifier and tunable output filter. Use SPICE simulation to estimate tuning range.

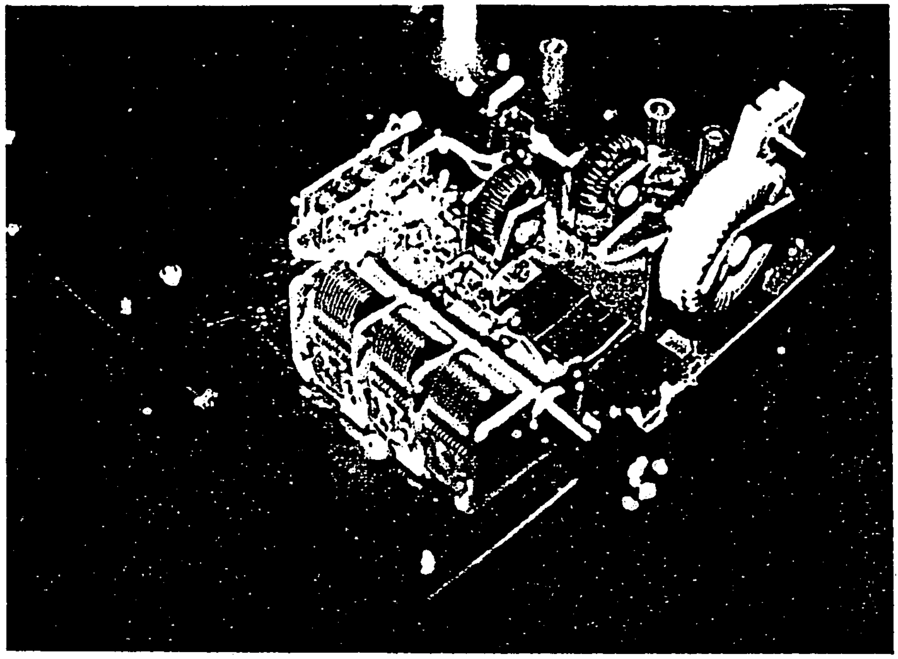

Figure 1. Class-E power amplifier with manual tuning.

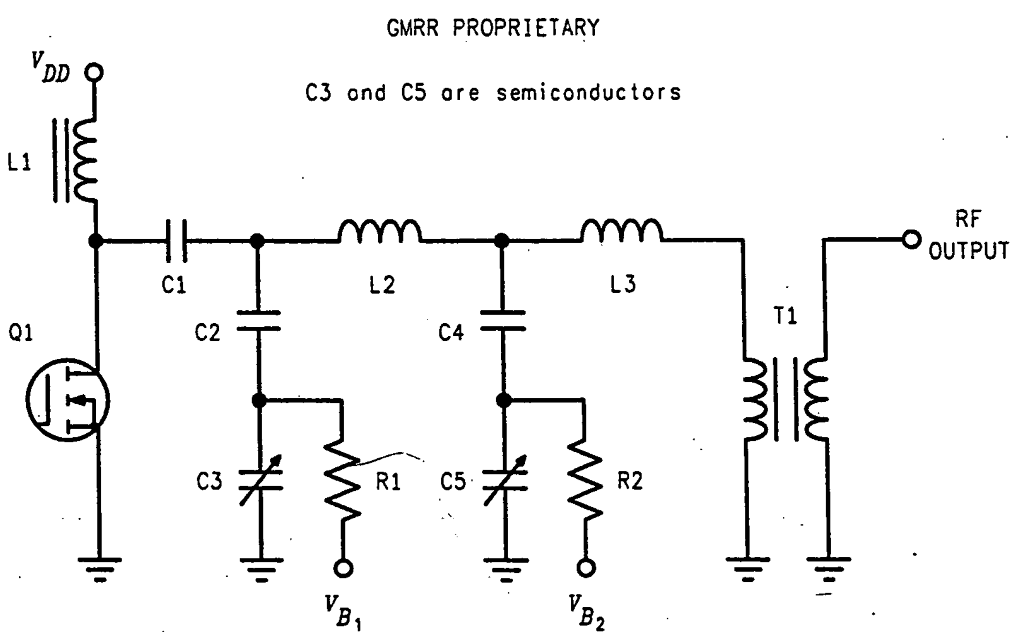

Figure 2. Class-E power amplifier with electronic tuning.

Task 3. Build Amplifier

Construct experimental amplifier based upon design from Task 2.

Task 4. Measure Performance

Test amplifier. Verify tunability via bias voltages. Measure power output and efficiency as a function of frequency.

5. FUTURE R&D

The principal use of the results of this investigation and experiment will be to increase the likelihood of a Phase-I award in the increasingly competitive SBIR program. It is impossible to identify a specific topic until they are announced by the agencies. However, candidate agencies can be identified by their past interests.

The most likely sponsor is the Department of Defense (DoD). Past DoD SBIR solicitations have included a number of high-efficiency amplifiers and frequency-agile tuners. For example, the last solicitation (99.1) included N99-164, (low-loss) "RF bandpass filters" and AF99-046 (high-efficiency) "Solid-state power amplifier modules for wideband (L-Ku) band array antennas". The Department of Energy and NASA are also potential sponsors. DoE is nearly always looking for means of improving efficiency in amplifiers for its particle accelerators, and NASA is nearly always looking for improved efficiency in transmitters for its deep-space probes.

A Phase-I contract will comprise a detailed investigation of the applicability of such a technique to the particular application of the customer. For example, it might deal with a VHF transmitter with a specified frequency band and power level. A subsequent Phase-II contract would then entail development of a working prototype for that application.

Even without an SBIR award, the results of the proposed Phase-0 investigation will be useful in securing private funding. For example, last year a potential client needed a frequency-agile high-efficiency amplifier for his induction-heating equipment.

5. COMMERCIALIZATION

Three principal areas for commercialization have been identified: Induction-heating, plasma generation including RF lighting, and radio communication. Our usual mechanism for commercialization is to work with a large company who does the production and marketing. GMRR has had good success in turning Phase-II SBIR technology developed for the Army into successful applications. The high-efficiency power-amplifier techniques developed in the IEWD Adaptive Jammer Power Amplifier (AJPA) project are being used in the following programs: